Adaptive Resource Allocation based on Artificial Bee Colony Algorithm and Simulated Annealing Algorithm for Multiuser OFDM systems

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Abstract

A novel joint subcarrier and power allocation scheme is proposed to solve the problem of adaptive resource allocation in multiuser OFDM system in this paper. And the proposed scheme first conducts the subcarrier allocation algorithm to obtain the set of subcarriers for each user, then carries out the power allocation algorithm to maximize the system capacity and improve the users' fairness. In the proposed subcarrier allocation algorithm, the set of subcarriers for each user is obtained by relaxing the users' rate proportionality constraint. Then a Artificial Bee Colony-Simulated Annealing (ABC-SA) power allocation algorithm based on the Artificial Bee Colony algorithm and the Simulated Annealing algorithm is proposed, which is the power allocation method among all users. And in the ABC-SA algorithm, the power allocation among each user's subcarriers is implemented by the method of equal power allocation. Finally, under the premise of full consideration of users' fairness, the maximum capacity of the multiuser OFDM system is obtained. The simulation results show that the proposed algorithm, compared with other algorithms in this paper, effectively improves the throughput of the multiuser OFDM system while taking into account the users' fairness, and the effectiveness of the proposed algorithm is proved.

Keywords

Multiuser Orthogonal Frequency Division Multiplexing; Adaptive Resource Allocation; Artificial Bee Colony Algorithm; Simulated Annealing Algorithm; Maximize The System Capacity.

1. Introduction

Orthogonal frequency division multiplexing (OFDM) [1] technology as one of the core technologies of the fourth generation wireless communication. It divides the whole channel frequency band into many orthogonal overlapping flat subchannels, which makes the high-speed serial data stream concurrently transmits in a plurality of flat subchannels by serial-to-parallel conversion. The Guard Interval (GI) and the Cyclic Prefix (CP) ensure the OFDM subcarriers are orthogonal and effectively reduce the Inter Symbol Interference (ISI) and the Inter Carrier Interference (ICI) from the multipath effect [2]. With the rapid development of micro electronic technology and digital signal processing technology, the digital modulation of OFDM signals can be came true in a low cost way by the Fast Fourier Transformation (FFT) and the Inverse Fast Fourier Transform (IFFT). Besides, the combination of OFDM technology and multiple access techniques also gives full play to its great potential in the communication system.

Reasonable allocation of OFDM system resources can be realized by adaptive resource allocation. The criteria of multiuser resource allocation are divided into two categories [3]. The first category is the Rate Adaptive (RA) criterion, which can maximize the system capacity under the premise that the transmission power is fixed. The second category is the Margin Adaptive (MA) criterion, which can minimize the transmission power of the system when the total transmission rate is fixed. So far, a number of excellent documents have emerged on the problem of maximizing the system capacity based on the RA criterion [4-9]. In [4], the Shen algorithm was proposed to achieve the maximum system capacity while ensuring the users' rate proportionality constraint. And the simulation results show that the Shen algorithm can almost achieve a fair value in strict sense. In [5], a joint algorithm of subcarrier and power allocation was proposed. This document first to meet the minimum rate requirements of users by using the Water-Filling algorithm, then the users that need the greatest rate will be allocated the subcarriers and the power preferentially. And the remaining power is finally allocated. In [6], under the premise that the users' fairness is guaranteed, a scheme of resource allocation based on subcarriers grouping was proposed. Simulation results show that the method in [6] can achieve the maximum system capacity, and the resource allocation is more flexible among users. In [7], the proposed Jang algorithm which indicates that the subcarriers are assigned to the users who have the largest channel gain on these subcarriers, can make the maximum system capacity. And it was also proved that the system capacity obtained by the method of equal power allocation is almost the same as the system capacity obtained by the Water-Filling algorithm. In [8], a two-step strategy for solving the problem of the multiuser OFDM resource allocation was proposed. Firstly, the subcarrier allocation for each user is implemented according to the channel gain. Then the SGPA algorithm is used to implement the allocation of bit and power. Finally, the algorithm maximizes the system capacity while taking into account the users' fairness. In [9], in order to maximize the system capacity, a power allocation scheme based on artificial fish swarm algorithm was proposed. The simulation results show that the proposed algorithm can ensure the users' high capacity and fairness.

In this paper, we will solve the problem of maximizing the system capacity based on the RA criterion and the users' rate proportionality constraint. Firstly, all subcarriers are assigned to all users in the subcarrier allocation by relaxing the users' rate proportionality constraint. And then under the condition that the subcarriers have been allocated, a ABC-SA algorithm based on Artificial Bee Colony (ABC) algorithm and Simulated Annealing (SA) algorithm is applied to allocate the power for each user in power allocation, wherein the power allocation among each user's subcarriers is implemented by the method of equal power allocation. Finally, we achieve the maximum capacity of the multiuser OFDM system while taking into account the users' rate proportionality fairness.

2. System Model

The adaptive model of the multiuser OFDM system is shown in Fig. 1.

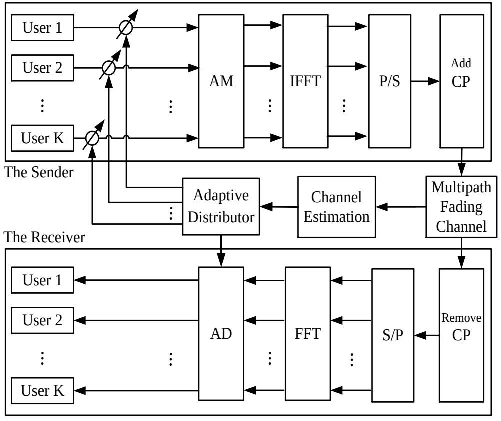

Fig. 1 The adaptive model of the multiuser OFDM system

In the Fig. 1, the sender estimates the real-time Channel State Information (CSI) by Channel Estimation. And the Adaptive Distributor sets the corresponding modulation parameters for each user's subcarriers, which is based on the real-time CSI and its built-in allocation algorithm. Then the corresponding adaptive modulation (AM) of each subcarrier is implemented. After that, the modulated data is transmitted to the receiver via IFFT, parallel-to-serial (P/S) conversion, the addition of the CP and the Multipath Fading Channel. After the receiver removes the CP, serial-to-parallel conversion (S/P) and FFI, the receiver demodulates each user's data by the adaptive demodulator (AD), wherein the demodulation operation is based on the parameters which are set by the AD.

According to Fig. 1, we assume that the multiuser OFDM system has K users and N subcarriers, the power spectral density of Additive Gauss White Noise (AGWN) is N_0, the bandwidth of the fading channel is B, the total transmission power is P_{total}, and $h_{k,n}^2$ is the channel gain for the k th user in the $n\,th$ subcarrier. According to the RA criterion and the reference [10], the optimization model considered in this paper can be formulated as

$$\max\sum_{k=1}^{K}\sum_{n=1}^{N}\frac{c_{k,n}B}{N}\log_2\left(1+\frac{p_{k,n}h_{k,n}^2}{N_0B/N}\right) \tag{1}$$

Subject to:

(a) $c_{k,n}\in\{0,1\}\quad\forall k,n$

(b) $p_{k,n}\geq 0\quad\forall k,n$

(c) $\sum_{k=1}^{K}c_{k,n}=1\quad\forall n$

(d) $\sum_{k=1}^{K}\sum_{n=1}^{N}c_{k,n}p_{k,n}\leq P_{total}$

(e) $R_1:R_2:\cdots:R_K=\lambda_1:\lambda_2:\cdots:\lambda_K$

As regards (a), it was noted that the value of $c_{k,n}$ is only 0 or 1. If the value of $c_{k,n}$ is 1, then the subcarrier is assigned to the user k; otherwise the subcarrier will not be allocated to the user k. The $p_{k,n}$ in the inequality (b) represents the allocated power value for the n th subcarrier of the k th user, and the inequality (b) indicates that the distributive power for each subcarrier is not less than 0. The equation (c) indicates that a subcarrier can only be assigned to one user. The inequality (d) indicates the sum of the distributive power for each subcarrier can not exceed the restrictive total transmission power P_{total}. In the equation (e), $\{\lambda_k\}_{k=1}^{K}$ is a group of preset users' rate proportionality constraint, which are applied to ensure the users' fairness, wherein the k th user's rate R_k can be denoted as

$$R_k=\sum_{n=1}^{N_k}b_{k,n} \tag{2}$$

$$b_{k,n}=\frac{c_{k,n}}{N}\log_2\left(1+\frac{p_{k,n}h_{k,n}^2}{N_0B/N}\right) \tag{3}$$

Where N_k represents the number of subcarriers to be allocated to the user k, $b_{k,n}$ is the number of bits to be allocated to the n th subcarrier of the k th user. In order to take into account the users' fairness, we set a fairness function *Fairness* to evaluate the fairness of the proposed algorithm under different number of users, as shown in the equation (4). From the equation (4), we can see that the closer the value of the fairness function *Fairness* is close to the maximum value 1, the better the users' fairness will be.

$$Fairness=\left(\sum_{k=1}^{K}\frac{R_k}{\lambda_k}\right)^2\Bigg/\left(K\sum_{k=1}^{K}\left(\frac{R_k}{\lambda_k}\right)^2\right) \tag{4}$$

3. Subcarrier Allocation

In this section, the subcarrier allocation algorithm is an improved algorithm for the subcarrier allocation algorithm in the reference [4]. Firstly, the subcarrier allocation algorithm determines the number of the subcarriers assigned to each user. Then the total transmission power is evenly assigned to all subcarriers. Finally, all the subcarriers are assigned to all users according to the channel gain and each user's rate proportionality constraint.

3.1 The demonstration of the number of subcarriers for each user

Since the proportion of the number of subcarriers allocated to each user is approximately equal to the final each user's rate proportionality. Then according to the constraint (e) in formula (1), we can get the following equation by relaxing the users' rate proportionality constraint.

$$N_1 : N_2 : \cdots : N_K \approx \lambda_1 : \lambda_2 : \cdots : \lambda_K \tag{5}$$

where $\{N_k\}_{k=1}^{K}$ represent the number of subcarriers that each user should be allocated, and N_k can be denoted as follows.

$$N_k = \left\lfloor N\lambda_k \Big/ \sum_{k=1}^{K} \lambda_k \right\rfloor \tag{6}$$

From the above formula, we can know that the number of the remaining subcarriers is $N_{rest} = N - \sum_{k=1}^{K} N_k$, and $N_{rest} < K$. The corresponding proof is as follows.

In the formula (6), $\lfloor X \rfloor$ is to round down to the nearest integer for *X*. And according to the formula (6), we can get $N\lambda_k \big/ \sum_{k=1}^{K} \lambda_k < \left\lfloor N\lambda_k \big/ \sum_{k=1}^{K} \lambda_k \right\rfloor + 1$, then $\sum_{k=1}^{K} N\lambda_k \big/ \sum_{k=1}^{K} \lambda_k < \sum_{k=1}^{K} \left\lfloor N\lambda_k \big/ \sum_{k=1}^{K} \lambda_k \right\rfloor + K$, thus $N < \sum_{k=1}^{K} N_k + K$. After transposition, we get that $N_{rest} < K$. Hence, we can conclude that the k th user can get at most $N_k + 1$ subcarriers. And the formula (5) is approximately valid when the number of subcarriers N is very large, further indicating that it is reasonable that the number of subcarriers allocated to each user is determined by the formula (6).

3.2 The subcarrier allocation algorithm

According to the equation (1), (2) and (3), we assume that there are K users and N subcarriers in the multiuser OFDM system. The spectral density of AWGN is N_0 , the bandwidth of the fading channel is B , the total transmission power is P_{total} . We set the users' rate proportionality constraint is $R_1 : R_2 : \cdots : R_K = \lambda_1 : \lambda_2 : \cdots : \lambda_K$, then the steps of the subcarrier allocation algorithm in this paper are as follows.

Step 1. Determine the number of subcarriers allocated to each user by the formula (6), denoted as $\{N_k\}_{k=1}^{K}$, and calculate the number of the remaining subcarriers N_{rest} .

Step 2. Initialization. Initialize the allocation matrix of subcarriers $c_{k,n} = 0, \forall k \in \{1, \cdots, K\}, \forall n \in \{1, \cdots, N\}$, the initial rate of each user $R_k = 0, \forall k \in \{1, \cdots, K\}$, the initial set of subcarriers $\Phi = \{1, 2, \cdots, N\}$. And calculate the average power $p = P_{total}/N$, then $p_{k,n} = p\ , \forall k, n$.

Step 3. Initial allocation. Search for the best subcarrier n for each user successively, namely, in the initial set of subcarriers $\Phi = \{1, 2, \cdots, N\}$, find out and allocate a subcarrier for each user, and each allocated subcarrier is a subcarrier with the maximum channel gain for each corresponding user. Then, $c_{k,n} = 1$, $N_k = N_k - 1$, $R_k = R_k + b_{k,n}$, and each allocated subcarrier will be removed from $\Phi : \Phi = \Phi - \{n\}$.

Step 4. When $\|\Phi\| > N_{rest}$, the algorithm continues to allocate the subcarriers. This step assumes the users' set is $\Lambda = \{1, 2, \cdots, \mathrm{K}\}$. After that, find out the user k with the smallest R_k/λ_k value in the set Λ , then judge whether the N_k of the user k is larger than 0. If $N_k > 0$, look for the subcarrier $n = \arg\max_{n\in\Phi} h_{k,n}^2$ for the user k and allocate the subcarrier n to the user k, besides, $c_{k,n} = 1$, $N_k = N_k - 1$, $R_k = R_k + b_{k,n}$, $\Phi = \Phi - \{n\}$. If $N_k < 0$, the user k will be removed from $\Lambda : \Lambda = \Lambda - \{k\}$, and find out another user k^* with the smallest R_{k^*}/λ_{k^*} value in the updated set Λ, then continue to judge and allocate the subcarriers for the user k^*.

Step 5. When $\|\Phi\| \le N_{rest}$, the remaining N_{rest} subcarriers are assigned, wherein each user can get at most one undistributed subcarrier. This step assumes the users' set is $\Omega = \{1, 2, \cdots, K\}$, after that, allocate one user for each remaining subcarrier. And compared with other users, each remaining subcarrier has the largest channel gain on the allocated user, that is to say, find out one user $k = \arg\max_{k\in\Omega} h_{k,n}^2$ for each remaining subcarrier n, then the remaining subcarrier n is assigned to the user k. Besides, $c_{k,n} = 1$, $R_k = R_k + b_{k,n}$, and the user k will be removed from $\Omega : \Omega = \Omega - \{k\}$.

The flow chart of the subcarrier allocation algorithm is shown in Fig. 2.

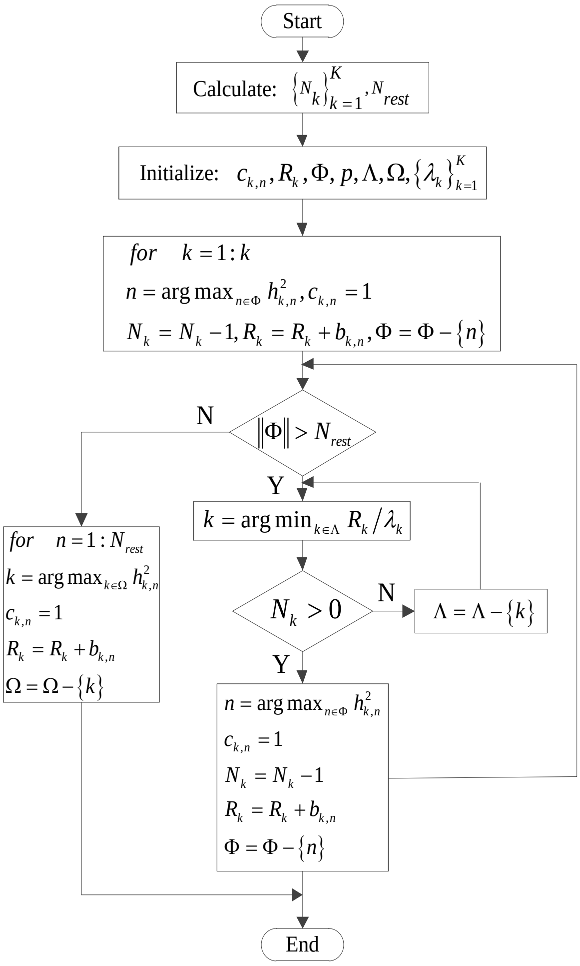

Fig. 2 The flow chart of the subcarrier allocation algorithm

In this section, we obtain the set of subcarriers for each user. And the subcarrier allocation algorithm just rough realizes the users' fairness, so the goal of achieving the users' rate proportionality fairness while maximizing system capacity needs to be achieved by the process of the power allocation in the section 4.

4. Power Allocation

From the section 3, we have got the result of the subcarrier allocation, which is the set of subcarriers for each user. And in this section, we will use the result of subcarrier allocation for power allocation.

The current intelligent algorithms mainly include the artificial fish swarm algorithm [11], the ant colony algorithm [12], the genetic algorithm [13], the ABC algorithm and the SA algorithm, etc. All of these algorithms are heuristic algorithm and they are derived from the imitation of the natural law, which provide a new opportunity to study the adaptive resource allocation for multiuser OFDM systems. As a swarm meta-heuristic algorithm, the ABC algorithm has many advantages such as simple structure, few adjustable parameters, strong robustness and high stability, etc. And the SA algorithm has the advantages of global optimization which can jump out of local extremum, and it is also simple and flexible. Therefore, we will use a hybrid algorithm based on the ABC algorithm and the SA algorithm to solve the problem of the power allocation among multiple users in this section.

4.1 The introduction of the ABC algorithm

In 2005, the Karaboga team put forward the ABC algorithm [14] to solve the problem of multivariable function optimization. The basic idea of the ABC algorithm is that the position of each nectar source is correspond to a candidate solution of the problem to be solved, and the optimization problem is abstracted to find out the optimal nectar source, then the optimal solution of the optimization problem is obtained by the ABC algorithm. In the ABC algorithm, the bees are divided into three categories. The employed bees, the onlookers and the scout bees, wherein the employed bees and the onlookers are responsible for the exploitation of nectar sources, and each nectar source and each employed bee are corresponding. Since the quality of the solution of optimization problem is related to the quantity of nectar sources, so the scout bees have the duty to excavate the nectar sources, which can insure that the number of the nectar sources species is not too small. Therefore, the ABC algorithm mainly includes the employed bees period, the onlookers period and the scout bees period. The corresponding search process is as follows.

Step 1. Initialization. In accordance with the form of the solution of the problem, generate $2SN$ nectar sources in the feasible region, and choose the optimal SN nectar sources as the initial marked nectar sources.

Step 2. The employed bees period. After the employed bees find these marked nectar sources, they will continuous search for new nectar sources by the formula (7). And compare the nectar amounts of different nectar sources, which is the process of searching for the optimal fitness value. Besides, the employed bees will choose the nectar sources with more nectar amounts to update the SN marked nectar sources by the method of greedy selection, and then share the updated SN marked nectar sources with the onlookers.

$$V_{ij} = x_{ij} + R(x_{ij} - x_{kj}) \tag{7}$$

In the above equation, j represents dimension and $j \in \{1,2,\cdots,D\}$, wherein D is the dimension of search space, R decides the disturbance amplitude and $R \in (-1,1)$, x_{ij} represents the original position of the nectar source i in the jth dimension, V_{ij} represents the new position of the nectar source i in the jth dimension, k is applied to provide the search direction and $k \in \{1,2,\cdots,SN\}, k \neq i$.

Step 3. The onlookers period. The onlookers use the updated SN marked nectar sources which are from the employed bees to select the suitable nectar sources in the way of roulette by the formula (8). Then search for new nectar sources in the vicinity of the selected suitable nectar sources by the formula (7). Besides, choose the nectar sources with more nectar amounts to update the SN marked nectar sources.

$$P_i = \mathrm{fit}_i \Big/ \sum_{j}^{SN} \mathrm{fit}_j \tag{8}$$

where fit_i is the nectar amounts of the ith nectar source, $\sum_{j}^{SN} \mathrm{fit}_j$ is the sum of the nectar amounts of all nectar sources, P_i is the probability of the ith nectar source that is selected.

Step 4. The scout bees period. When the employed bees have exploited some nectar sources for $Limit$ times and the nectar amounts of these nectar sources don't change. Then the corresponding employed bees give up these nectar sources and transform into the scout bees, and they will randomly search for new nectar sources to replace these nectar sources which have the constant nectar amounts. Finally, update and determine the final SN marked nectar sources in this cycle.

Step 5. If the termination condition is not satisfied, then go to the Step 2.

4.2 The introduction of the SA algorithm

The SA algorithm [15] derives from the process of solid annealing in the physics. According to the thermodynamic principle, the internal energy of solid can also be changed when the temperature of solid is changed. Hence, the SA algorithm simulates the internal energy of solid as the objective function $f(X)$ and lets the temperature T as the control parameters to execute the search operation of the SA algorithm. Furthermore, the SA algorithm's Metropolis criterion allows the objective function to accept the solutions which are worse than the current solutions with a certain probability. Then it is possible to make the algorithm out of local extremum and achieve the effect of global optimization. Thereupon, under a temperature control parameter, the SA algorithm repeatedly execute to generate new solutions, calculate the increment of objective function and judge whether to accept the new solution. The specific steps of the SA algorithm are as follows.

Step 1. Initialization. Initialize the initial value of the temperature control parameter T_0, the initial solutions X_0, the termination conditions S. And the iterations of the SA algorithm for each T_k ($k \in \{0,1,\cdots,M-1\}$, assuming that there are M different temperature parameter values), which also be known as the length of the Mapkob chain and can be denoted as $\{L_k\}_{k=0}^{M-1}$. Then calculate the initial values of the objective function $f(X_0)$.

Step 2. When $T = T_k$, the algorithm will perform the following search procedure for L_k times.

1) Randomly jitter around the current solution X_k to generate the new X_{k*}, and calculate the value of the objective function of the new X_{k*}, denoted as $f(X_{k*})$.

2) Calculate the increment of objective function $\Delta = f(X_{k^*}) - f(X_k)$. If $\Delta \le 0$, then the current solution is X_{k^*}, and $f(X_k) = f(X_{k*})$. If $\Delta > 0$, then determine the probability of accepting new solutions according to the Metropolis Criterion, denoted as $P = \exp\left[-\left(f(X_{k*}) - f(X_k)\right)/T_k\right]$, and generate a random number ϕ in the interval $(0,1)$. Then if $P \ge \phi$, the current solution is X_{k^*}, and $f(X_k) = f(X_{k*})$. If $P < \phi$, the current solution and the value of the objective function don't change.

3) If the above search procedure has executed for L_k times, then judge whether the termination condition S is satisfied or not. If the termination condition S is satisfied, then the current solution is output and the algorithm is finished. Otherwise, go to the Step 3.

Step 3. Reduce the temperature of the current temperature parameter T_k and generate new temperature control parameters T_{k+1} and L_{k+1}, then go to the Step 2.

4.3 The power allocation based on the ABC-SA algorithm

Although the ABC algorithm is suitable for solving combinatorial optimization problems, it will inevitably fall into the situations of local optimal and search stagnation. On the contrary, the SA algorithm precisely has the ability to jump out of local optima for global searching and it also avoids the phenomenon of search stagnation. Thus according to the shortcomings of the ABC algorithm and the advantages of the SA algorithm, we apply the ABC-SA algorithm, which is based on the ABC algorithm and the SA algorithm, to carry out the power allocation. Due to the number of subcarriers N is much larger than the number of users K in the actual wireless communication system, and in order to reduce the complexity of the ABC-SA algorithm for power allocation among N subcarriers, we apply the ABC-SA algorithm for power optimization among K users. We assume that $\{P_{k,\ total}\}_{k=1}^{K}$ represent the power allocated to the K users, then the power allocation among K users can be denoted as $P = P_{1,total} + P_{2,total} + \cdots + P_{k,total}$ (P is the total transmission power P_{total}). According to the formula (1) and (3), we can know that we only get the $\{P_{k,\ total}\}_{k=1}^{K}$ that can't achieve the maximum system capacity and what we need is the values of all the $p_{k,n}$, that is to say, what we need is the power allocated to each subcarrier. Then we must find a way to get the the values of all the $p_{k,n}$ by $\{P_{k,\ total}\}_{k=1}^{K}$. Actually, we found a way to solve the problem, that is the method of equal power allocation.

It is generally known that the optimal power allocation scheme for each user's subcarriers can be obtained by using the Water-Filling algorithm. But the Water-Filling algorithm needs to calculate the Water-Filling threshold by the way of mathematical search. And the Water-Filling threshold will be updated periodically, which undoubtedly increases the complexity of the algorithm and the system burden. Hence we apply the equal power allocation method to allocate the power for each user's subcarriers in this paper. And in reference [7], it has been proved by simulation that the system capacity of the equal power allocation method is almost identical to that of the Water-Filling algorithm. Therefore, the power allocation among each user's subcarriers can be denoted as

$$p_{k,n} = c_{k,n} P_{k,total} / n_k \tag{9}$$

In the formula (9), $p_{k,n}$ represents the allocated power value for the n th subcarrier of the k th user, $c_{k,n}$ is the same as the constraint (a) in the formula (1), n_k is the number of subcarriers assigned to the user k.

From the above, we can make sure that the problem we need to solve is to apply the ABC-SA algorithm to find out a K-dimensional nectar source $\{P_{k,\ total}\}_{k=1}^{K}$ which is composed of K users' power. Then on the basic of this K-dimensional nectar source $\{P_{k,\ total}\}_{k=1}^{K}$ and the set of subcarriers for each user, the power allocation among each user's subcarriers is implemented in the way of the equal power allocation method according to the equation (9). And at the same time, the system capacity is maximized in condition of the user's rate proportionality constraint. Therefore, in order to find out the optimal nectar source, and for the purpose of balancing the system capacity and the users' fairness, we combine the formula (1), (2), (3) and (4) to set a fitness function as follows.

$$Fitness = \left(\sum_{k=1}^{K} R_k\right)\left(\left(\sum_{k=1}^{K} \frac{R_k}{\lambda_k}\right)^2 \Bigg/ K\sum_{k=1}^{K}\left(\frac{R_k}{\lambda_k}\right)^2\right) \tag{10}$$

In the following part, we will use the ABC-SA algorithm to find out the optimal K-dimensional nectar source $\{P_{k,\ total}\}_{k=1}^{K}$. Then we can obtain each user's subcarrier set under the condition of the users' rate proportionality constraint, and we can also achieve the maximum system capacity. The other parameters of this part is consistent with the subcarrier allocation part. The specific process of the power allocation based on the ABC-SA algorithm is as follows.

Step 1. Set the initial parameters. The number of nectar sources is SN, the maximum exploitation times of each nectar resources is $Limit$, the current exploitation times of each nectar resource is $Bas = 0$, the maximum number of cycles is $Maxcycle$, the initial number of cycles is $cycle = 0$, the simulated annealing parameter is m, the temperature control parameter of the simulated annealing can be doneted as $\{T_{k+1} = T_k \times m\}_{k=1}^{Maxcycle}$.

Step 2. The scout bees generate initial nectar resources. The scout bees generate $2SN$ K-dimensional nectar sources (the sum of the K elements of each K-dimensional nectar source is P_{total}) in the search field by random search. After that, calculate the fitness value of the $2SN$ K-dimensional nectar sources by the formula (10). Then select SN optimum nectar sources, which have the larger fitness value than other nectar sources, as marked nectar sources. Besides, select a maximum fitness value and the corresponding nectar source as the optimal fitness and optimal marked nectar source, respectively.

Step 3. The employed bees period. The employed bees find the SN marked nectar sources from the scout bees and search for SN new nectar sources in the neighborhood of the SN marked nectar sources by the formula (7). After get the SN new nectar sources, the SA algorithm is applied to replace the greedy selection strategy for the neighborhood search. In the SA algorithm, under the temperature control parameter T_k, perform the following operations for each new nectar source.

1) According to the formula (10), calculate the fitness value of each new nectar source and the fitness value of the original nectar source that generates this new nectar source.

2) If the fitness value of the new nectar source is larger than the fitness value of the original nectar source that generates this new nectar source, then select the new nectar source as marked nectar source and abandon the original nectar source that generates this new nectar source. Otherwise, calculate the probability P of accepting new solutions and generate a random number ϕ in the interval $(0,1)$, then go to step 3).

3) If $P<\phi$, then the marked nectar source does not change, and its Bas=Bas+1. If $P\geq\phi$, select the new nectar source as marked nectar source and abandon the original nectar source that generates this new nectar source.

Finally, get the updated SN marked nectar sources, the current exploitation times of each nectar resource Bas and the fitness values of the updated SN marked nectar sources. Then share these information with the onlookers.

Step 4. The onlookers period. The onlookers use the information from the employed bees to select the suitable nectar sources in the the way of roulette by the equation (8). After get the selected SN nectar sources, the SA algorithm is applied to update the SN selected nectar sources and the value of Bas for each selected nectar source. And the process of the SA algorithm in this step is the same as the Step 3. Then get the updated SN marked nectar sources and the current exploitation times of each nectar resource Bas.

Step 5. The scout bees period. According to the maximum exploitation times $Limit$ of each nectar source and the current exploitation times Bas of each nectar source from the onlookers, determine whether or not to appear the scout bees. If the the current exploitation times Bas of a nectar resources is greater than the maximum exploitation times $Limit$, namely, this nectar source’s $Bas>Limit$. Then the employed bee that correspond to this nectar source will transform into the scout bee. And the current marked nectar resource will be abandoned and the scout bee will search for new nectar resources to replace the current marked nectar resource. Finally, obtain the final SN marked nectar sources in this cycle.

Step 6. Update the optimal fitness and the optimal marked nectar source. According to the formula (10), calculate the fitness values of the SN marked nectar sources from the scout bees. And find out the optimal fitness value and its optimal marked nectar source in this cycle, then judge whether to update the optimal marked fitness and the optimal marked nectar source. After that, $cycle = cycle + 1$.

Step 7. If $cycle = Maxcycle$, then output the optimal marked nectar source, Otherwise, the T_k is updated to get the new temperature control parameter T_{k+1} and go to the Step 3.

Step 8. According to the obtained optimal marked nectar source from the Step 7, calculate the system capacity of multiuser OFDM system by the formula (1), (2), (3) and (9).

And in order to make the ABC-SA power allocation algorithm easier to be understood, Fig. 3 shows the flow chart of the power allocation based on ABC-SA algorithm in this paper.

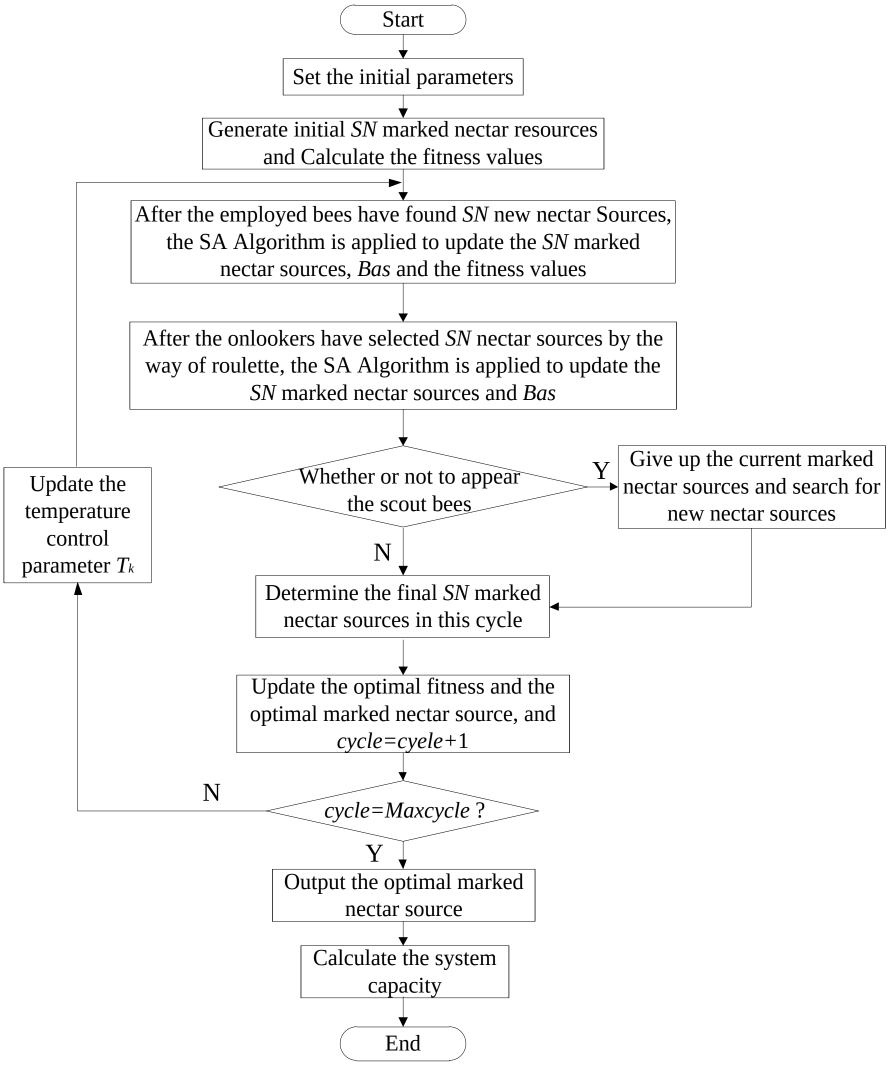

Fig. 3 The flow chart of the ABC-SA power allocation algorithm

5. Simulation Analysis

In this paper, we use the subcarrier allocation and the power allocation based on the ABC-SA algorithm to solve the problem of adaptive resource allocation for the multiuser OFDM system. In the simulation, we assume that the number of users is K=8, the number of subcarrier is N=64, the spectral density of AWGN is $-80\,\text{dB}\cdot\text{W/Hz}$, the total channel bandwidth is B=1 MHz and the total transmission power is $P_{\text{total}}=1$ W. About the parameters of the ABC-SA algorithm, $SN=100$, $Limit=30$, $T_1=100$, $Maxcycle=100$, $m=0.9$. The simulation model is based on the 6 path Rayleigh fading channel model with frequency selectivity.

When the number of users K varies from 2 to 12 in the multiuser OFDM system, the different system capacities by using the ABC-SA algorithm in this paper compared to the only ABC algorithm, the Shen algorithm in reference [4], the artificial fish swarm algorithm (AFSA) in reference [9] and the OFDM-TDMA algorithm, which are the results of 500 Monte Carlo Simulations, are shown in Fig. 4. In the Fig. 4, in order to better compare the performance of these algorithms, we assume that all users have the same transmission rate, that is to say, the users' rate proportionality constraint is $R_1:R_2:\cdots:R_K=1:1:\cdots:1$. It can be easily seen from the Fig. 4 that the system capacity of the ABC-SA algorithm is always higher than that of other algorithms. And due to the influence of the multiuser diversity gain, the system capacities of all the algorithms become larger with the increase of the number of users except for the OFDM-TDMA algorithm. When the number of users is 12, the system capacity of the ABC-SA algorithm is about $0.05\,\text{bit/s}\cdot\text{Hz}^{-1}$ higher than that of the only ABC algorithm, about $0.17\,\text{bit/s}\cdot\text{Hz}^{-1}$ higher than that of the AFSA algorithm in reference [9], about $0.28\,\text{bit/s}\cdot\text{Hz}^{-1}$ higher than that of the Shen algorithm in reference [4] and about $0.89\,\text{bit/s}\cdot\text{Hz}^{-1}$ higher than that of the OFDM-TDMA algorithm.

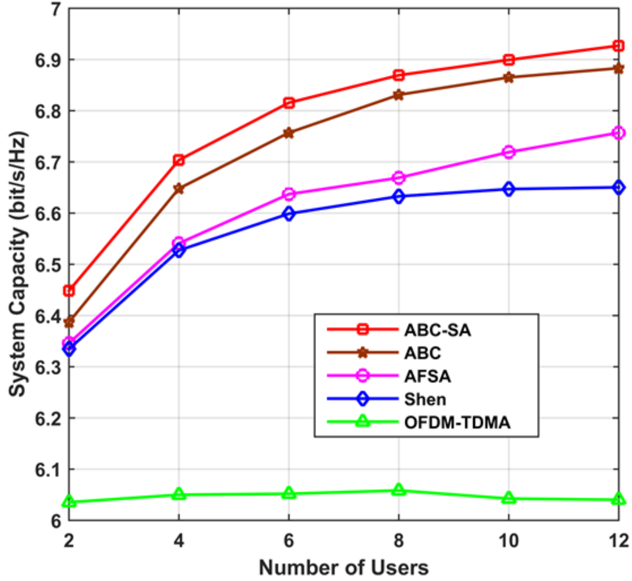

Fig. 4 The system capacity comparison of different algorithms

From the reference [4], we can know that the Shen algorithm has been verified by simulation that it can almost strictly implement the users' rate proportionality constraint. Then any algorithm can be evaluated whether the algorithm is fair by comparing with the Shen algorithm. Fig. 5 is the fairness comparison of the proposed algorithm and the Shen algorithm by using the formula (4). And when the number of users K varies from 2 to 12, it can be seen from the figure that the fairness of the Shen algorithm is infinitely close to 1. But the fairness of the proposed algorithm is between 0.9988-0.9852, which can be interpreted as that the subcarrier allocation relaxes the users' rate proportionality constraint to maximize the system capacity. Besides, the remaining N_{rest} subcarriers also increase the freedom degree of the subcarrier allocation, which reduces the fairness of the proposed algorithm.

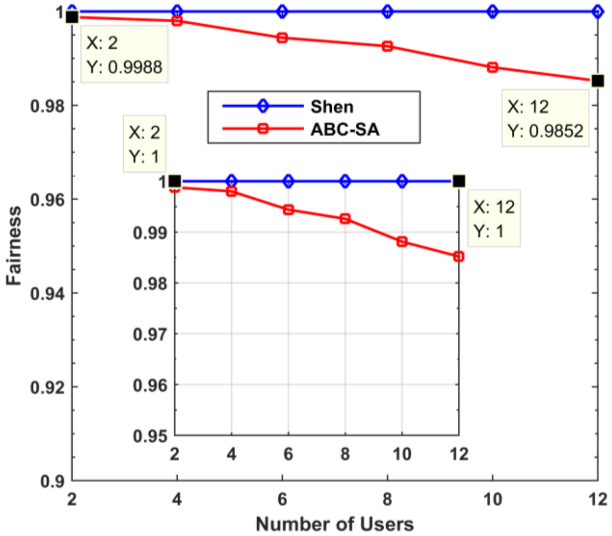

Fig. 5 The fairness comparison between the ABC-SA algorithm and the Shen algorithm

Without loss of generality, when the number of users is $K = 8$ and the average subchannel SNR is 20 dB, we set the users' rate proportionality constraint as $R_1 : R_2 : \cdots : R_8 = 6:4:2:1:1:1:1:1$. Then the case of the capacity allocation for each user is shown in Fig. 6. From the Fig. 6 and Fig. 5, we can see that although the proposed algorithm is not as fair as the Shen algorithm in reference [4], the capacity assigned to each user by the ABC-SA algorithm is more closer to the Shen algorithm than the only ABC algorithm, the AFSA algorithm in reference [9] and the OFDM-TDMA algorithm, and which indicates that the ABC-SA algorithm is more fair than the other algorithms in this paper. Then we can come to the conclusion that the ABC-SA algorithm not only ensures the high capacity for each user, but also improves the users' fairness. In conjunction with Fig. 4, 5 and 6, we can conclude that although the fairness of each user is reduced in subcarrier allocation, the system capacity is maximized while the users' fairness is further improved by means of the proposed ABC-SA algorithm in this paper.

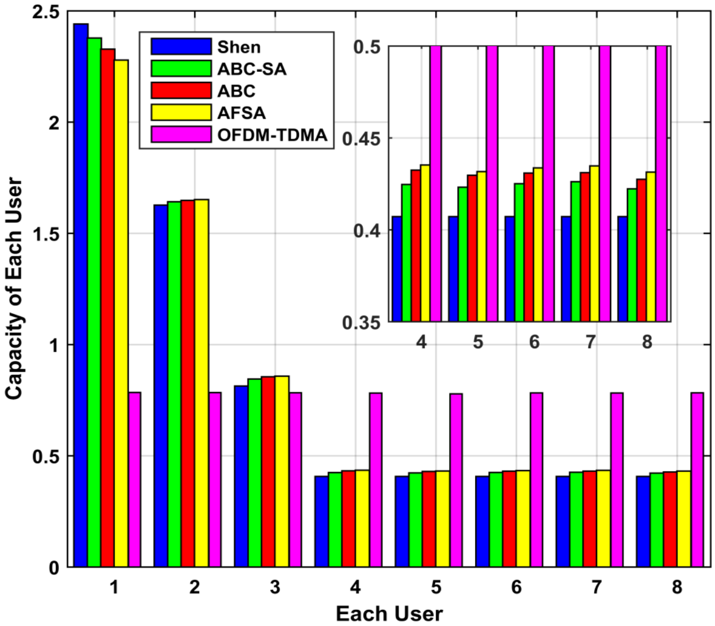

Fig. 6 when $K = 8$, the comparison of each user's capacity

6. Conclusion

In this paper, we propose a novel joint subcarrier and power allocation scheme. In the subcarrier allocation, we use an improved subcarrier allocation algorithm for subcarrier allocation. In addition, we combine the ABC algorithm with the SA algorithm to put forward a hybrid ABC-SA power allocation algorithm to solve the problem of the power allocation. Simulation results show that the proposed algorithm can commendably solve the problem of adaptive resource allocation based on the RA criterion for multiuser OFDM systems. And from the simulation results, we can conclude that the proposed algorithm is a compromise between maximizing system capacity and the users' fairness. Besides, the proposed scheme provides an effective way for the further research on adaptive resource allocation for multiuser OFDM.

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References

[1] Shanzhi Chen, Zhanyang Ren, and Bo Hu, et al: Resource Allocation in Downlink OFDM Wireless Systems with User Rate Allowed Regions, Wireless Personal Communications, Vol. 80(2015) No.1, p.429-445.

[2] Var Puthnith, Shrestha Robin, and Kim JaeMoung: Improved Power Allocation to Enhance the Capacity in OFDMA System for Proportional Resource Allocation, The Journal of Korean Institute of Communications and Information Sciences, Vol. 38(2013) No.7, p.580-591.

[3] Zhendong Yin, Shufeng Zhuang, and Zhilu Wu, et al: Rate Adaptive Based Resource Allocation with Proportional Fairness Constraints in OFDMA Systems, Sensors, Vol. 15(2015) No.10, p.24996-25014.

[4] Zukang Shen, J.G. Andrews, and B.L. Evans: Adaptive resource allocation in multiuser OFDM systems with proportional rate constraints, IEEE Transactions on Wireless Communications, Vol. 4(2005) No.6, p.2726-2737.

[5] Wentao Zhao, Shaowei Wang: Joint subchannel and power allocation in multiuser OFDM systems with minimal rate constraints, International Journal of Communication Systems, Vol. 27(2014) No.1, p.1-12.

[6] Zhanyang Ren, Shanzhi Chen, and Bo Hu, et al: Proportional resource allocation with subcarrier grouping in OFDM wireless systems, IEEE Communications Letters, Vol. 17(2013) No.5, p.868-871.

[7] Jiho Jang, Kwang Bok Lee: Transmit power adaptation for multiuser OFDM systems, IEEE Journal on Selected Areas in Communications, Vol. 21(2003) No.2, p.171-178.

[8] Abd-Elnaby Mohammed, Sedhom Germien G, and Messiha Nagy W, et al: Fair subcarrier-power allocation scheme for multiuser multicarrier systems, Journal of Central South University, Vol. 22 (2015) No.8, p.3033-3041.

[9] Zhao Wang, Youming Li, and Bin Chen, et al: OFDMA adaptive resource allocation based on fish swarm algorithm, Acta Physica Sinica, Vol. 62 (2013) No.12, p.128802-1-128802-7.

[10] Ye Wang, Qinyu Zhang, and Naitong Zhang: Resource allocation based on subcarrier exchange in multiuser OFDM system, Science China Information Sciences, Vol. 56 (2013) No.1, p.1-14.

[11] Mingzhu Liu, Xin Li, and Mingyu Zhang, et al: Research on Artificial Fish Swarm Algorithm with Cultural Evolution for Subcarrier Allocation, International Journal of Hybrid Information Technology, Vol. 8 (2015) No.6, p.279-288.

[12] Lei Xu, Yaping Li, and Qianmu Li, et al: Proportional fair resource allocation based on hybrid ant colony optimization for slow adaptive OFDMA system, Information Sciences, Vol. 293(2015), p.1-10.

[13] Nitin Sharma, A.S. Madhukumar: Genetic Algorithm Aided Proportional Fair Resource Allocation in Multicast OFDM Systems, IEEE Transactions on Broadcasting, Vol. 61 (2015) No.1, p.16-29.

[14] Archana C, Rejith K.N: Rate adaptive resource allocation in OFDMA using BEES algorithm, International Journal of Research in Engineering and Technology, Vol. 3(2014) No.15, p.14-18.

[15] Lei Xu, Xunzhao Zhou, and Qianmu Li, et al: Energy-efficient resource allocation for multiuser OFDMA system based on hybrid genetic simulated annealing, Soft Computing, (2016), p.1-8.